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Cost and Performance Report

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Joint Small-Arms Range Remediation

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AA	Atomic Absorption
AEC	Army Environmental Center
ASI	Advanced Sciences, Inc.
BRAC	Base Realignment and Closure
CAAA	Clean Air Act Amendments
CATEX	Categorical Exclusion
COTR	Contracting Officer's Technical Representative
CWA	Clean Water Act
DESA	Defense Evaluation Support Activity
DoD	Department of Defense
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESTCP	Environmental Security Technology Certification Program
g	Grams
Gal/ft^2	Gallons per square foot
HASP	Health and Safety Plan
HOAc	Acetic Acid
HCl	Hydrochloric Acid
ITRC	Interstate Technology and Regulatory Cooperation
K/Wh	Kilowatt hours
M	Million
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
NaOH	Sodium Hydroxide
NEPA	National Environmental Policy Act
NFESC	Naval Facilities Engineering Service Center
OSHA	Occupational Safety and Health Act
P/F	Plate-and-Frame Filter
PPE	Personal Protection Equipment

LIST OF ACRONYMS (continued)

ppm	Parts per million
REC	Record of Environmental Consideration
RCRA	Resource Conservation and Recovery Act
RSD	Relative Standard Deviation
S/S	Stabilization/Solidification
TCLP	Toxicity Characteristic Leachate Procedure
WET	Wet Extraction Test
VBF	Vacuum Belt Filter

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Several individuals and organizations participated in this demonstration and provided review, guidance, and information that were valuable to the success of this project. Details of points of contact are provided in Appendix A.

- Richard O'Donell and Lisa Miller from the Army Environmental Center
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- Richard Kunter from Advanced Sciences, Inc. (ASI)
- Thomas Leggiere and Russell Foyle from ContraCon Northwest, Inc., Vendor 1
- Craig Jones from Brice Environmental Corporation (BESCORP), Vendor 2
- John Verner from the Defense Evaluation Support Activity (DESA)
- Mark Bricka from the U.S. Army Corps of Engineers, Waterways Experiment Station

In addition, Hazen Research Inc. provided specialized metallurgical laboratory support and guidance on evaluating mineral beneficiation techniques; and, the Fort Polk administration provided support and facilitation throughout the course of the demonstration.

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1.0 EXECUTIVE SUMMARY

This Environmental Security Technology Certification Program (ESTCP) demonstration conducted by the Naval Facilities Engineering Service Center (NFESC) and the Army Environmental Center (AEC) removed lead and other heavy metals from small-arms range soils by a combination of physical separation and acid leaching. Physical separation processes are effective for range maintenance activities involving removal of particulate metals such as bullets and bullet fragments from berm soil, and also as a pretreatment when combined with acid leaching to remediate the soil to cleanup standards required for site closure. Physical separation alone may not sufficiently clean the soil to meet cleanup standards but it reduces the volume of soil requiring acid leaching, and reduces the load on the leaching process. Subsequent acid leaching can attain cleanup standards.

The technology was demonstrated between August and December 1996 on soils from Range 5 at Fort Polk, an Army Base near Leesville, Louisiana. Range 5 is an active 300-meter small-arms range that mainly has been used for M-16 rifle training and contains soil and contamination of the type and quantity typically found at several DoD ranges. Two vendors were asked to demonstrate their variations of treatment trains for physical separation and acid leaching. Vendor 1 was asked to use acetic acid (i.e. weak acid) leaching and Vendor 2 was asked to use hydrochloric acid (i.e. strong acid) leaching. The two vendors were given total metals targets to achieve the Toxicity Characterization Leaching Procedure (TCLP) criterion for lead without the use of stabilization agents for the processed soil. Vendor 1's target was 1,000 mg/kg. The target was reduced to 500 mg/kg for Vendor 2 to better meet the TCLP criterion.

- ***Vendor 1 (Acetic Acid Leaching).*** Vendor 1 processed a total of 263 tons of soil over a period of 24 days by physical separation and acetic acid leaching at an average processing rate of 2.8 tons/hour. This system processed range soil to meet the total lead targets and TCLP only on the first day of processing, when it removed approximately 93% of total lead, 93% of total copper, 77% of total zinc, and 70% of total antimony. Subsequently, however, both total and leachable lead levels rose incrementally due to buildup of lead in the regenerated leachate caused by inadequate precipitation. Total lead was reduced from an average of 2,828 mg/kg in raw soil to 122-1,443 mg/kg in processed soil.

- ***Vendor 2 (Hydrochloric Acid Leaching).*** Vendor 2 processed a total of 835 tons of soil over a period of 18 days by physical separation and hydrochloric acid leaching at an average processing rate of 6.3 tons/hour. This system consistently met total and TCLP lead targets. It removed from range soil an average of 96% total lead, 97% total copper, 89% total zinc and 60% total antimony. Total lead was reduced from an average of 4,117 mg/kg in raw soil to an average of 165 mg/kg in processed soil. Leachable lead levels, as measured by TCLP, were reduced to an average of 2 mg/L.

The operating inefficiencies experienced by Vendor 1 made cost interpretation from that demonstration difficult. The demonstration by Vendor 2 provided a better indicator of costs, which amounted to $1,400/ton for the 835 tons removed. Fixed costs of $830/ton were high but these would be reduced for a full-scale implementation. Full-scale costs were estimated at $170/ton for a 10,000-ton site, of which $70/ton were fixed costs. Routine range maintenance may involve only physical separation to remove

bullets and bullet fragments from the impact berms. Costs for physical separation alone were estimated to be approximately $59/ton for a 10,000-ton site, including fixed costs of $16/ton.

Offsite landfilling and on-site solidification/stabilization are two comparative technologies often considered for addressing elevated metal levels in small-arms ranges. Landfilling removes the hazard from the site while solidification/stabilization immobilizes metals in the soil. At sites with less than about 2,600 tons of soil, landfilling is the cheapest option. Solidification/stabilization is always cheaper than separation/leaching but the potential for liability remains. Separation/leaching removes soil heavy metals offsite, and eliminates long-term liability by providing property restoration without the presence of metals. This allows greater flexibility for future use. The technology components of physical separation/leaching are generally available and relatively ease to use.

2.0 TECHNOLOGY DESCRIPTION

Physical separation is used to remove particulate metals and acid leaching to remove the metals that are present as very fine particulates or molecular/ionic species bound to the soil matrix. These techniques commonly have been used for many years in the mining industry for separating metals from ores and, more recently, in the remediation industry for removing contaminants by soil washing.

Physical separation and acid leaching are particularly useful at sites where metals are present as particulates, e.g., small-arms ranges or battery recycling sites. First, oversize debris such as rock, that typically has low concentrations of metals is removed and cleaned by washing or leaching with a dilute acid solution. Metal fragments that may be suitable for offsite recycling are then separated from the bulk soil based on particle size and density. The remaining lighter, smaller soil consisting of sands, silts, and clay, very fine metal particulates, and bound molecular or ionic metals can be effectively treated with acid leaching. In light of site specific conditions, the process should ideally be optimized by characterization and treatability testing using site soils.

Physical separation and acid leaching operations use commercial off-the-shelf equipment and technology. A variety of vendors is available to implement the technology (USAEC, 1997). Two vendors were selected to demonstrate a combination of physical separation and acid leaching that can be used to remove lead and other heavy metals from small-arms range soil.

ContraCon Northwest, which utilized acetic acid leaching, is referred to as Vendor 1 in the body of this report. Brice Environmental Services Corporation (BESCORP), which utilized hydrochloric acid leaching, is referred to as Vendor 2.

2.1 PHYSICAL SEPARATION

The functional requirements for physical separation are to remove oversize debris (if any) and separate bullets and bullet fragments from soil to allow recycling of the metals and more efficient subsequent treatment of the soil. Five classes of physical characteristics provide a practical basis for separating particles. These are particle size (screening), particle hydrodynamics (settling velocity), particle density (gravity separation), surface properties of particles (flotation), and magnetic properties (magnetic separation). The attributes of these common particle separation techniques are summarized in Table 1. The effectiveness of different physical separation methods depends on the size and density characteristics and the concentration of lead in different size ranges of the soil.

2.2 DEWATERING

With the exception of dry screening, physical separation techniques use water to facilitate transfer and separation of the solid particles. Dewatering often is required to recover and reuse water. It is important to recover this water because it may contain elevated levels of soluble and suspended metals. Commonly used processes for dewatering include filtration, expression, centrifugation, and sedimentation (or thickening). A combination of these methods typically is used to obtain successively drier solids.

Table 1. Key Attributes of Common Particle Separation Techniques

	Technique				
	Size Separation	**Hydrodynamic Separation (Classification)**	**Density (Gravity) Separation**	**Froth Flotation**	**Magnetic Separation**
Basic Principal	Various diameter openings allow passage of particles with different effective size	Different settling rates due to particle density, size, or shape	Separation due to density differences	Particles are attracted to bubbles due to their surface properties	Magnetic susceptibility
Major Advantage	High-through put, continuous processing with simple, inexpensive equipment	High-throughput, continuous processing with simple, inexpensive equipment	High-through-put, continuous processing with simple, inexpensive equipment	Very effective for fine particles	Can recover a wide variety of materials when high gradient fields are used
Limitations	Screens can plug; fine screens are fragile; dry screening produces dust	Difficult when high proportions of clay, silt, and humic materials are present	Difficult when high proportions of clay, silt, and humic materials are present	Particulate must be present at low concentration	High capital and operating cost
Typical Implementation	Screens, sieves, or trommels (wet or dry)	Clarifier, elutriator, hydrocyclone	Shaking table, spiral concentrator, jig	Air flotation columns or cells	Electromagnets, magnetic filters

Sources: U.S. EPA, 1995, EPA/540/R-95/512.

2.3 ACID LEACHING

After physical separation, most of the coarse particulate metals have been removed from the bulk soil. Lead and other metals are still present in the soil either as fine particulates or as molecular or ionic species bound to the soil matrix. The functional requirements for acid leaching are to remove metals from the soil to meet total and leachable metal concentration requirements while producing the minimum amount of process residuals. For acid leaching to succeed, the leaching solution must be able to remove metals to the required cleanup level, reach the required cleanup level with a minimum number of contacting cycles, produce a minimum volume of waste leaching solution, selectively dissolve the metals of concern but not the matrix, and provide compatibility with moderate cost materials of construction.

Acid leaching is often performed as a continuous process and involves at least four vessels. In the leaching tank the acid solution is mixed with the soil to leach out the metals. Contact time requirements vary based on the type of soil and type of metal encountered. Small-arms range berms tend to be highly variable in terms of soil texture and the level of metals accumulation. Therefore, some degree of overdesign is advisable to maintain the desired processing rate for the plant.

The soil slurry is pumped from the leach tank to the clarifier, where the solids settle out and are discharged from the bottom. A flocculant may be added to enhance settling. The overflow from the clarifier is the leachate containing the solubilized metals. This overflow goes to a precipitation tank, where the solubilized metals are recovered. Precipitants used for metals recovery include hydroxide, phosphate, carbonates, sulfate, and sulfide.

The treated leachate may then flow into a separate clarifier tank for settling of the precipitate. The mixing of precipitant and coagulant with the leachate is fairly fast (15 to 60 min). Settling may require 2 to 4 hours at overflow rates of 300 to 700 gal/ft2 of surface area per day (Lanouette, 1977). Some of the initial precipitate formed may be recirculated to the mixing tank, where the older precipitate particles provide a seed on which new precipitate can grow.

In the clarifier, the precipitate floc settles down to form a sludge with only 1 to 2% solids, which must be dewatered before it is hauled off-site for disposal or recycling. A plate-and-frame (P/F) filter or a vacuum belt filter (VBF) are typically used. A filter aid, such as diatomaceous earth, may be required to prevent clogging of the filter cloth. Lead may be recovered from the dewatered sludge if acceptable to a smelter operator. The overflow from the clarifier is recycled back to the leach tank after being refortified with acid.

2.4 TECHNOLOGY DEMONSTRATED

Process schematics of the treatment trains demonstrated at Fort Polk are shown in Figure 1 (Vendor 1) and Figure 2 (Vendor 2).

2.5 HEALTH AND SAFETY

Physical separation and acid leaching processing presents some potential hazard sources for operating personnel. Processing requires soil transfer and mixing equipment and involves chemical handling and material transfer operations. However, this is performed with standard construction and chemical handling equipment and does not pose any hazards beyond those normally encountered during industrial activities. The potential hazards can be mitigated using standard safety procedures and equipment. Health and safety concerns are the air pathway with the target pollutants being lead dust and acid fumes. Level D Personal Protection Equipment (PPE) is the norm.

2.6 COMPETING TECHNOLOGIES

Offsite landfilling and on-site Solidification/Stabilization are two comparative technologies often considered for addressing elevated metal levels in small-arms ranges. Neither of these is a permanent solution. Landfilling removes the hazard from the site while Solidification/Stabilization immobilizes metals in the soil.

Separation/leaching removes soil heavy metals for recovery as a potential economic resource, and eliminates long-term liability by providing property restoration without the presence of heavy metals. This allows greater flexibility for future use. The technology components of separation/leaching are generally available and relatively ease to use.

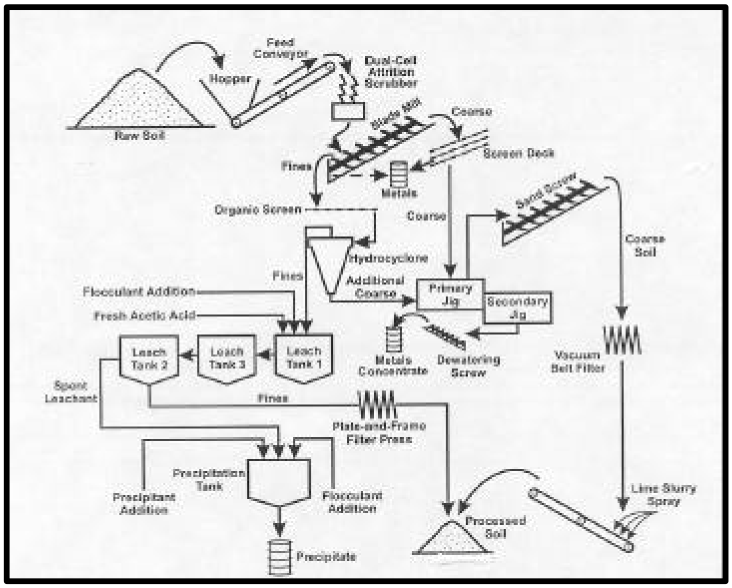

Figure 1. Vendor 1 Schematic (Physical Separation and Acetic Acid Leaching)

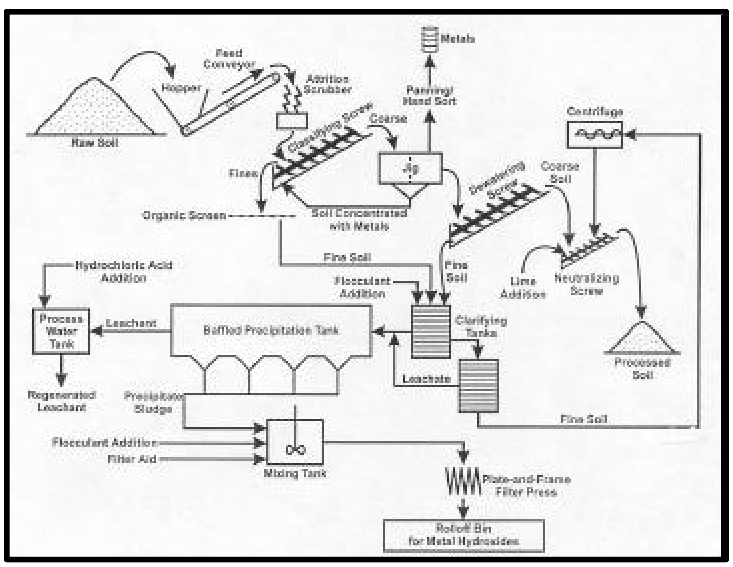

Figure 2. Vendor 2 Schematic (Physical Separation and Hydrochloric Acid Leaching)

2.7 TREATABILITY TESTING

Treatability testing is a necessary preliminary activity to operation of a physical separation/acid leaching process. This testing provides data that can be used as a basis for design and implementation. The key elements of treatability tests include the following:

- ***Prescreening Characteristics.*** Historical records and site characterization data provide information about the nature and extent of metals accumulation and the engineering properties of the matrix.

- ***Testing Goals and Data Quality Objectives.*** The goals of treatability testing are to determine process feasibility, select a physical separation approach, optimize leaching system parameters, and determine design parameters.

- ***Sample Selection.*** The sample selection process should be designed to give a representative sample that is large enough to allow testing but not so large that the laboratory is unable to handle the material.

- ***Soil Characterization.*** To provide direction to the treatability tests, it is necessary to determine the particle-size distribution of the berm soils, coupled with the metal concentrations in each size range.

- ***Process Optimization.*** Depending on the particle size of the metals and the goals for processing, relatively elaborate bench-scale tests may needed. For example, bench-scale hydrocyclones and jigs may need to be tested to optimize the process. If acid leaching is required, all aspects of the leaching cycle need to be fully tested and optimized.

- ***Data Analysis and Interpretation.*** The data gathered should be used to generate a process flow diagram with a material balance.

- ***Schedule.*** The treatability tests should allow time to obtain analytical results that cover a wide range of operating conditions. A second set of testing should focus on a narrower range of conditions to confirm results from the first set and to optimize and better determine design parameters.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The overall goal of the demonstration was to evaluate the efficiencies of two different acids for leaching. Vendor 1 was asked to use acetic acid leaching and Vendor 2 was asked to use hydrochloric acid leaching. Each vendor was given the following performance objectives:

- Design and mobilize their respective equipment at Fort Polk, Louisiana and process up to 1,000 tons of small-arms range soil at an average continuous rate of 5 tons/hr.

- Process the range soil to meet the Toxicity Characterization Leaching Procedure (TCLP) criterion of 5 mg/L or less of lead. No criteria were set for other metals, but the removal of copper, zinc, and antimony was also tracked.

- Achieve the TCLP criterion without the use of stabilization agents. The two vendors were therefore given total metals targets for the processed soil. Vendor 1's target was 1,000 mg/kg. The target was reduced to 500 mg/kg for Vendor 2 to better meet the TCLP criterion.

- Ensure that the processed soil is physically and chemically suitable for reuse in an active berm.

3.2 PHYSICAL SETUP AND OPERATION

Process schematics of the treatment trains demonstrated at Fort Polk are shown in Figure 1 (Vendor 1) and Figure 2 (Vendor 2). Mobilization and assembly of each vendor's plant on-site (not including transportation) took 14 days. The field activities related to the demonstration were conducted between August and December 1996. The demonstration was conducted in an old parking lot approximately 2 miles away from the range by road to avoid other firing range exercises with the potential to extend into Range 5. Also, the demonstration site was located near an available power supply. The pilot scale footprint of the equipment sets used a 90-ft x 130-ft (27.4 m x 39.6 m) impervious pad. The physical separation and acid leaching technology was demonstrated sequentially, first by Vendor 1. Site preparation activities included constructing a side-bermed, impervious, asphalt-paved operations pad and a storm-water holding pond, and providing major utility connections, security fencing, and weather shelters for the soil.

Vendor 1's leaching process was based on acetic acid (i.e. weak acid) chemistry. Vendor 2's process was based on hydrochloric acid (i.e. strong acid) chemistry. The goal was not to compare the two vendors, but to evaluate the suitability of the two acids for processing small-arms range soils.

The plants were scheduled to operate 10 hours/day, including 2 hours to reach steady state.

The demonstration was a joint effort between NFESC and AEC. BDM Engineering Services, Inc. (BDM), the mission support contractor for Fort Polk, prepared the National Environmental Policy Act (NEPA) documentation that examined potential impacts from the field activities. A Record of Environmental

Consideration (REC) was approved in April 1996. Battelle, under contract to NFESC, conducted the independent evaluation of the technology application at Fort Polk (Battelle, 1997a).

3.3 SAMPLING PROCEDURES

The primary objective of sampling was to ensure that the two critical process performance objectives concerning TCLP and total lead in the final processed material were met. Sampling was conducted daily or for every 80-ton batch of raw soil stockpile to determine whether or not the final processed soil was suitable for return to the berm. Secondary sampling objectives were to evaluate the lead removal efficiencies of the two major elements of the process (physical separation and leaching) as well as evaluate the removal of other undesirable metals (antimony, copper and zinc) in the various process streams. Once reasonable steady state processing was achieved (typically after 2 hours of daily processing), sampling and monitoring were conducted on raw and final processed soil, input and output streams, and intermediate process streams. Obtaining representative samples from heterogeneous process streams was the main sampling challenge. When particulate or fragment metal contaminants are present, the "nugget effect" makes sampling difficult and can dramatically alter the analytical result. A sampling strategy was employed whereby grab samples were taken and combined to from a composite sample that was large enough to be representative of the maximum particle size present. Complete details of demonstration sampling are included in the technology evaluation report (Battelle, 1997a).

3.4 ANALYTICAL PROCEDURES

Standard EPA Method 1311 was used for TCLP analysis of soil samples. Standard EPA SW-846 Method 3051 was used for digestion of samples for total metals analysis, with a few modifications. The sample size for digestion was increased from 2 g to 8 g to enhance the representativeness of samples containing particulate metals. To improve the recovery of antimony, hydrochloric acid, as well as nitric acid, was used for the digestion. The digestates were analyzed by ICP according to SW-846 Standard Method 6010. In addition, on-site testing using an XRF analyzer was performed on some samples to provide real-time, approximate analyses. Complete details of demonstration analytical procedures are included in the technology evaluation report (Battelle, 1997a).

3.5 DEMONSTRATION SITE/FACILITY BACKGROUND

The physical separation and acid leaching technology was demonstrated on soils from Range 5 at Fort Polk, an Army Base near Leesville, Louisiana. Range 5 is an active 300-meter small-arms range that has been used mainly for M-16 rifle training. The range has three berms, the last of which runs along the edge of a wetland. Fort Polk was selected for the demonstration because it is environmentally proactive and has active ranges that contain soil and contamination of the type and quantity typically found at several DoD ranges.

3.6 DEMONSTRATION SITE/FACILITY CHARACTERISTICS

The Fort Polk Range 5 site has been contaminated with lead from the firearms discharged during routine training exercises. Lead is present mostly in the berm soils (bullet pockets) located behind the firing targets.

Range 5 consists of three berms about 580 feet in length. Berm 1 has the lowest height of the berms at about 2 feet. Berm 2 has the highest crest and ranges from 5 to 8 feet. Berm 3 is about 5 feet in height. Berm soil for the two demonstrations was excavated from Berm 3, and consisted of the top 18 inches of soil taken from the top of the berm to about 20 feet in front of the berm. Additional soil with elevated levels of lead can be found between the berms. Background lead levels in Fort Polk soils appeared to be less than 50 ppm. In addition to lead, site characterization tests showed that copper, antimony, and zinc are present in the site soils.

To evaluate lead distribution and the amenability of the soil to physical separation, a detailed characterization was performed by Hazen Research for Battelle (see Figure 3) on a representative 30-gallon composite sample of berm soil collected from Range 5. Dry screening tended to underestimate the fines content of the soil because balls of fine clay were retained on the coarse screens. Figure 3 also shows the results of additional characterization conducted by Battelle to determine the particle size and lead distribution in various fractions and the amenability of the lead in these fractions to physical separation:

- The raw soil feed from the berm had a lead assay of almost 0.5%.

- The +10-mesh coarse fraction constituted 2.3% of the berm material, but contained almost 80% of the original lead. Therefore, most of the lead in the range soil was recoverable by relatively simple size or gravity separation equipment. About 3% of the lead was amenable to magnetic separation.

- When the coarse fraction was further separated into metals (magnetic and nonmagnetic) and gravel (float), the gravel was found to contain enough leachable lead to fail the TCLP test.

- The +10 mesh fraction constituted 98% of the berm material, but contained only 20% of the lead. The middlings and tailings (predominantly soil) fractions retained most of the lead and both streams failed the TCLP test. The +10-mesh fraction did not contain much lead amenable to gravity separation.

- Physical separation alone was not sufficient to meet target criteria. The !10-mesh material contained sufficient fine particulate and/or ionic lead to require removal by leaching.

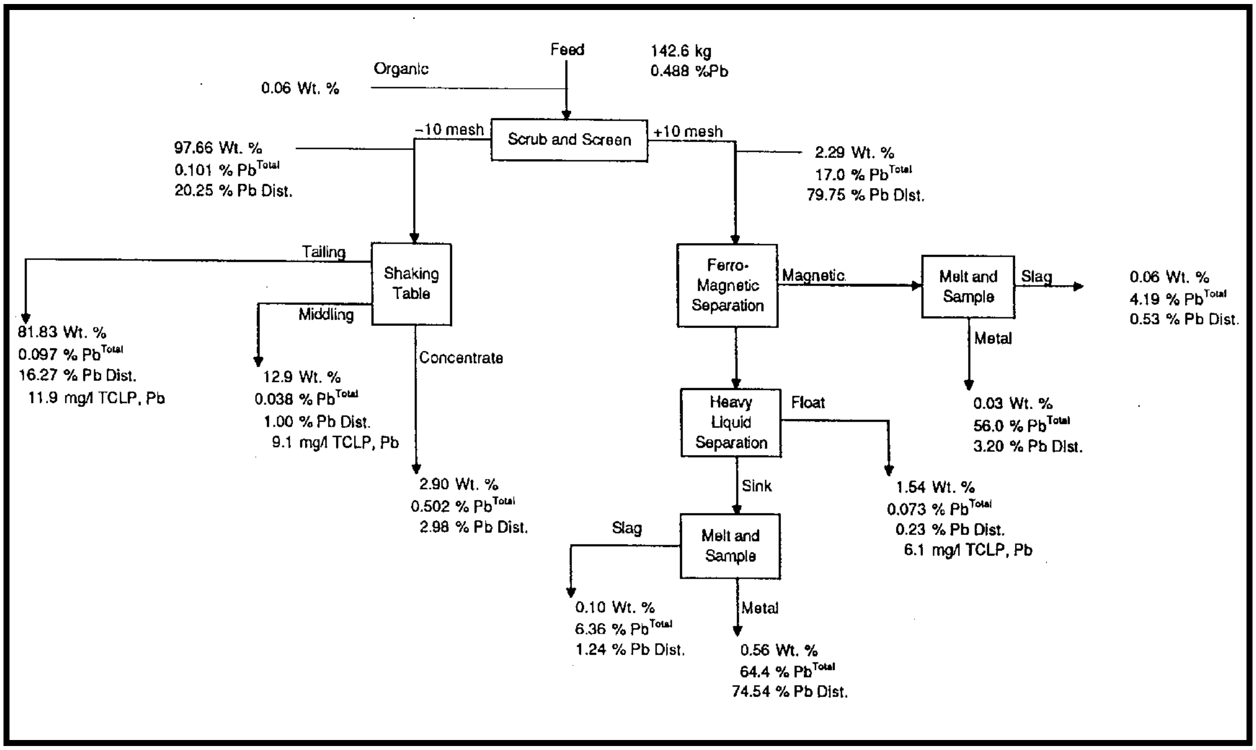

Figure 3. Range 5 Soil Characterization

4.0 PERFORMANCE ASSESSMENT

For both demonstrations, the precision of the sample preparation and analytical procedures for determining total metal concentrations in the raw and processed soil streams was well within the predetermined target of 25% relative standard deviation (RSD).

The precision of the TCLP analysis for raw soil was outside the target range for many of the raw soil samples. Multiple aliquots of composite samples were analyzed to average out this variability. The precision of the TCLP analysis was within limits for most of the processed soil analyses.

Routine method blank analyses and instrument calibrations showed that background and other analytical interferences were minimal.

4.1 VENDOR 1 PERFORMANCE

Vendor 1 processed 263 tons of Range 5 soil by physical separation and acetic acid leaching over a period of 24 working days (operating 65% of the scheduled time) at an average processing rate of 2.8 tons/hour. On the first day of processing, the processed soil met the total and TCLP lead targets. Approximately 93% total lead, 93% total copper, 77% total zinc, and 70% total antimony were removed during this initial processing effort, indicating that acetic acid has the potential to remove heavy metals to target levels. However, the residual lead content of subsequently processed soil quickly rose. Both total and leachable lead levels in the processed soil rose incrementally as lead levels in raw soil increased, and lead levels built up in the regenerated leachant because of too acidic operating conditions and inadequate precipitation. Total lead was reduced from an average of 2,828 mg/kg in raw soil to 122-1,443 mg/kg in processed soil. In addition, the processed soil appeared unsuitable for return to the range due to inadequate dewatering and neutralization. At times, the site workforce wore Level C PPE (respirators) while sampling processed soil. The processed soil that did not pass the TCLP was sent to a landfill. Demobilization was completed on-site in 10 days.

4.2 VENDOR 2 PERFORMANCE

Vendor 2 processed 835 tons of Range 5 soil by physical separation and hydrochloric acid leaching over a period of 18 days (operating 94% of the scheduled time) at an average processing rate of 6.3 tons/hour. The plant operated at steady state during the entire demonstration and consistently processed soil to meet total and TCLP lead targets. Total lead was reduced from an average of 4,117 mg/kg in the raw soil to an average of 165 mg/kg in the processed soil. Leachable lead levels as measured by TCLP were reduced to an average of 2 mg/L. Processing removed an average of 96% total lead, 97% total copper, 89% total zinc, and 60% total antimony from the range soil. The processed soil was recycled to reconstruct the berm, which supported revegetation well. Demobilization was completed on-site in 10 days.

Figure 4 shows the lead assays of the various process streams. Most of the metals that were removed by the process were collected in the jig bed (stream MN) and in the precipitate sludge (stream P). In this jig, the metal fragments, instead of sinking into the jig concentrate, were retained on top of the jig sieve along with the ragging. These metal fragments were hand-sorted and removed by an operator.

The organic matter separated from the classifier overflow also showed high concentrations of lead. This organic matter was blended with the final processed soil.

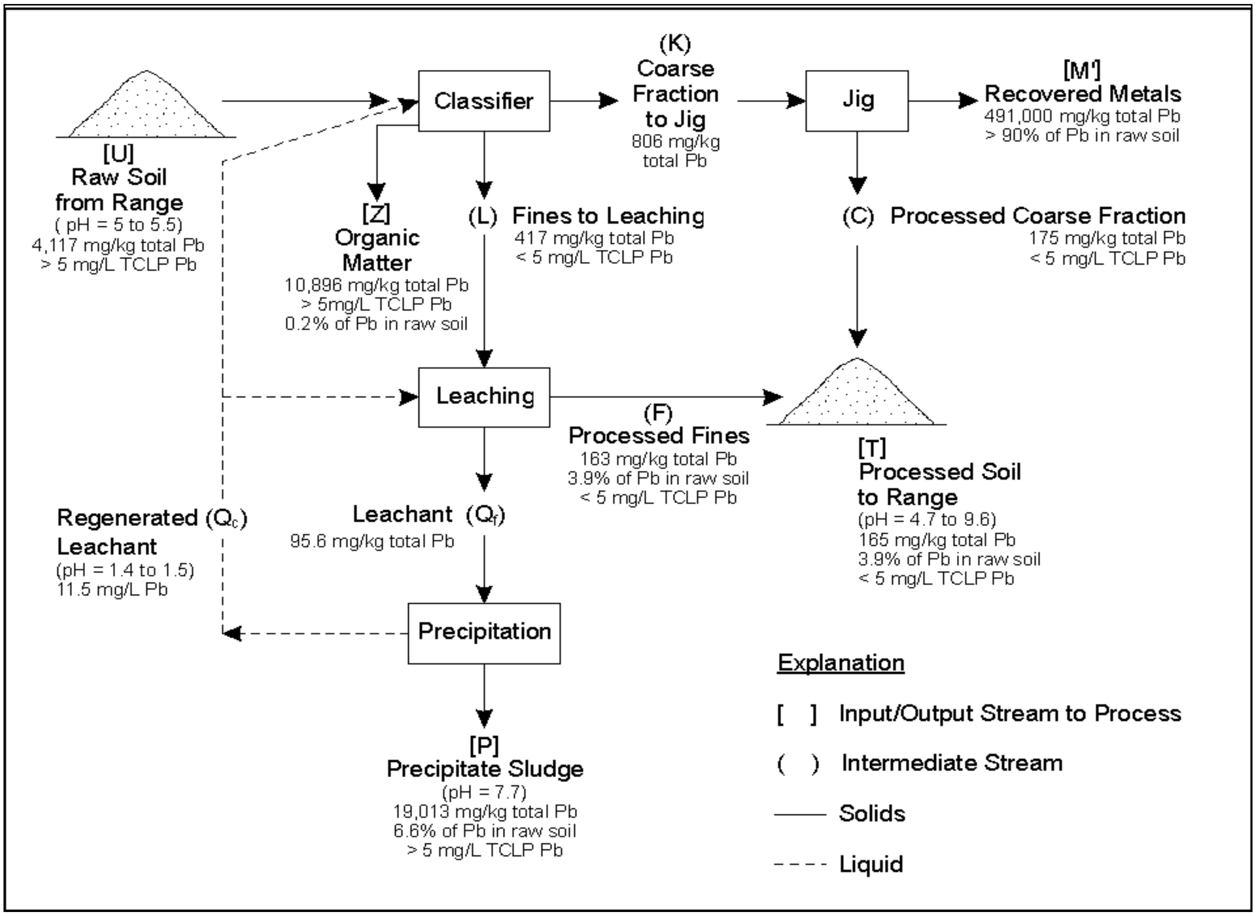

Figure 4. Distribution of Lead in Various Process Streams (Vendor 2)
(Physical Separation and Hydrochloric Acid Leaching)

Both coarse (stream C) and fine (stream F) processed fractions contained low levels of lead. These two fractions were combined to form the final processed soil (stream T), which was neutralized and returned to the range. Precipitation was conducted efficiently at a pH of around 9.5 by adding sodium hydroxide. Precipitation reduced the lead content from 96 mg/L in the leachate (stream Q_f) to 11.5 mg/L in the regenerated leachant (stream Q_c). The processed soil had a loose texture and appeared to be suitable for reuse in the active berm at Range 5.

The mass distribution of lead in the input and output streams in the plant is summarized in Table 2. Most of the lead was collected in the jig bed rather than in the jig concentrate. About 7% of the lead was collected in the precipitate sludge. The organic matter isolated from the soil contained a high concentration of lead but its mass was not significant. About 4% of the lead in the raw soil was residual in the processed soil. In an attempt to close the mass balance for the process (see Table 2), the jig bed solids (stream MN)

were sampled and analyzed for lead. However, representative sampling was difficult and the results obtained are subject to large error. The mass balance is skewed mainly by the high variability of the lead concentration in the jig bed metals.

Table 2. Mass Distribution of Lead in Various Process Streams (Vendor 2)

Proces s Stream	Stream Description	Moisture Content (%)	Mass of Process Stream (kg)[a]	Average Lead Concentratio n (mg/kg)	Mass of Lead (kg)	Mass Percentag e of Lead (%)[b]
U	raw soil	9.1	757,507	4,117[c]	2,836	100
T	processed soil	22.8	868,825	165	111	3.9
P	precipitate sludge	62.9	26,672	19,013	188	6.6
Z	organic matter	40.0	800[d]	10,896	5.2	0.2
M[e]	jig bed metals	5.0[e]	7,859[f]	491,900[g][h]	3,673	129.5[h][i]

(a) Total mass of process streams are on a wet weight basis.
(b) Overall balance equation : U = T + P + Z + Metals.
(c) Concentration of total lead in the raw soil varied considerably from day-to-day.
(d) Mass of material in this stream was estimated to be 1 % of the total feed.
(e) This stream had particulate metals from jig bed and small amount of soil; moisture content assumed at 5 %.
(f) Mass of material in this stream estimated from weights of drums reported by off-site recycling facility.
(g) Lead in recovered metals stream measured by pyrometallurgical analysis conducted on 3 samples from this stream.
(h) This number has highest uncertainty because of high variability of this stream and analytical limitations.
(i) This value theoretically cannot be greater than 100.

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5.0 COST ASSESSMENT

This section describes the budget cost estimates (+30% to -15% accuracy) to process small-arms range soils based on the Fort Polk demonstration.

The hydrochloric acid process costs provided the best basis for projecting the costs for a routine range maintenance or close-out remediation operation. Table 3 shows the costs incurred during the Fort Polk demonstration. The total cost for the demonstration at Fort Polk that processed 835 tons of berm soil was approximately $1.17M, at an average cost of around $1,400/ton. Fixed costs accounted for nearly two-thirds of this total cost. At larger sites, especially under non-demonstration conditions, these fixed costs could be spread over the greater amount of soil processed, and thus the unit cost per ton of soil processed would be expected to be much lower.

Because small-arms range sites have 10-20,000 tons of soil, a cost projection for a hydrochloric acid remediation of 10,000 tons soil is shown in Table 4. It is assumed that the same size plant as used in the demonstration (20-tons/hr quoted capacity) would be used for sites up to 10,000 tons, and that the performance of the processing plant will be maintained at a higher throughput of 20 tons/hr. Implicit in the scale-up cost projection is the assumption that the plant would be required to meet similar processing targets (5 mg/L TCLP lead and 500 mg/kg of total lead). The projected unit cost for remediation of 10,000 tons of berm soil is approximately $170/ton.

Routine maintenance may involve only physical separation to remove bullets and bullet fragments from the impact berms. Most of the bullets can be separated from berm soils by simply screening them out. However, for a 10,000-ton quantity of berm soil, the amount of rock present in the oversize fraction from the screening operation can be significant. The cost of shipping this fraction to a lead smelter is also significant, but it can be reduced by concentrating the lead using gravity separation techniques. The projected costs for a physical separation process are presented in Table 5, and these include gravity separation of coarse (oversize) and sand fractions (not the fines). The projected unit cost for range maintenance of 10,000 tons of berm soil using physical separation only at a processing rate of 20 tons/hr is approximately $59/ton.

The costs of alternative technologies for small-arms range remediation (landfill disposal, stabilization/solidification) were obtained using industry standard cost estimates (R.S. Means, 1996) and these are compared with the cost of physical separation and hydrochloric acid leaching in Table 6.

Table 3. Costs Incurred for Vendor 2 Demonstration (Physical Separation and Hydrochloric Acid Leaching)

Item	Basis	Demonstration Costs 835 tons
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, & other permitting	$73,199
Site Characterization (Site)	Planning, sampling, and analyses	$56,171
Vendor Selection (Site)	Selection and contracting, plan preparation	$135,686
Bench-Scale Testing (Vendor)	1 representative sample	$17,739
Site Preparation & Support (Site)	Pad construction and accessory rentals	$150,839
Engineering & Administrative (Vendor)	Administrative and assessment	$41,571
Transportation (Vendor)	Plant and personnel mobilization	$173,692
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$23,825
Decontamination and Demobilization (Vendor)	Disassembly, decontamination, and demobilization	$20,000
Total Fixed Costs		$692,722
Variable Costs		
Soil Excavation/Hauling (Vendor)	Backhoe equipment, excavation/hauling	$12,419
Equipment Lease (Vendor)	25% depreciation over 4 cleanups	$233,075
Labor (Site)	1 site superintendent for 300 hours	$18,000
	1 health and safety officer for 300 hours	$15,000
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$750
	Water, 49,300 gal @ $8.07/kgal	$398
	Phone, $220/month	$440
Labor (Vendor)	1 supervisor for 300 hours	$51,845
	2 engineers for 300 hours each	
	1 chemist for 300 hours	
	5 technicians for 300 hours each	
Chemicals (Vendor)	HCl acid, 5,200 gal @ $0.60/gal	$3,141
	NaOH, 5,850 gal @ $0.60/gal	$3,517
	Diatomaceous earth, 11,300 lb @$0.53/lb	$6,044
	Flocculant, 1,000 gal @ $3.31/gal	$3,311
	Hydrated lime, 1,275 lb @ $0.40/lb	$510
Consumables / Supplies (Vendor)	PPE, gloves, tarps, accessories	$8,235
Sampling & Analyses (Site)	Accessories, other equipment rentals	$19,983
- Labor (Site)	1 supervisor for 300 hours	$18,000
	2 technicians for 300 hours each	$18,000
- Analyses (Site)	240, sample prep & TCLP analyses	$57,000
	529, sample prep & total metals analysis	
Residuals, Waste Shipping/Handling (Vendor)	Bulk solid waste & recovered metals credit	$9,008
Effluent Treatment (Site)	Wastewater, 0 gal @ $1.25/gal	$0
Total Variable Costs		$478,676
Total Project Costs		**$1,171,398**
Total Cost/Ton of Soil		**$1,402**
Variable Cost/Ton of Soil		**$573**

Table 4. Scale-up Costs of Vendor 2 Process
(Physical Separation and Hydrochloric Acid Leaching)

Item	Basis	Scale-Up Costs 10,000 tons
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, other permitting	$73,199
Site Characterization (Site)	Planning, sampling, and analyses	$56,171
Vendor Selection (Site)	Selection and contracting, plan preparation	$135,686
Bench-Scale Treatability Tests (Vendor)	1 representative sample	$17,739
Site Preparation and Support (Site)	Pad construction and accessory rentals	$150,839
Engineering and Administrative (Vendor)	Administrative and assessment	$41,571
Transportation (Vendor)	Plant and personnel mobilization	$173,692
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$23,825
Decontamination and Demobilization (Vendor)	Disassembly, decontamination and demobilization	$20,000
Total Fixed Costs		$692,722
Variable Costs		
Site Excavation / Hauling (Vendor)	Backhoe equipment, excavation & hauling	$124,190
Equipment Lease (Vendor)	25% depreciation over 4 cleanups	$233,075
Labor (Site)	1 Superintendent/HSO for 480 hours	$28,800
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$1,125
	Water, 80,000 gal @ $8.07/kgal	$646
	Phone, $220/month	$660
Labor (Vendor)	1 supervisor for 480 hours	$134,400
	1 engineer for 480 hours each	
	1 chemist for 480 hours	
	3 technicians for 480 hours each	
Chemicals (Vendor)	HCl acid, 62,275 gal @ $0.35/gal	$21,796
	NaOH, 70,060 gal @ $0.44/gal	$30,826
	Diatomaceous earth, 50 tons @ $800/ton	$40,000
	Flocculant, 7,200 gal @ $2.20/gal	$26,347
	Hydrated lime, 8 tons @ $89/ton	$712
Consumables / Supplies (Vendor)	PPE, gloves, tarps, accessories	$50,994
Sampling & Analyses (Site)	Accessories, other equipment rentals	$34,873
- Labor (Site)	1 supervisor for 480 hours	$28,800
	1 technician for 480 hours	$14,400
- Analyses (Site)	360, sample prep & TCLP analysis	$86,040
	800, sample prep & total metals analysis	
Residuals, Waste Shipping / Handling (Vendor)	Bulk solid waste & recovered metals credit	$110,180
Effluent Treatment (Site)	Wastewater, 22,000 gal @ $1.25/gal	$27,500
Total Variable Costs		$995,364
Total Project Costs		**$1,688,086**
Total Cost/Ton of Soil Processed		**$169**
Variable Cost/Ton of Soil		**$100**

Table 5. Projected Costs for Physical Separation Only

Item	**Basis**	**Soil Screening Costs** 10,000 tons
Processing Duration		2 months
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, & other permitting	$20,000
Site Characterization (Site)	Planning, sampling, and analyses	$1,000
Vendor Selection (Site)	Selection and contracting, plan preparation	$25,000
Bench-Scale Treatability Tests (Vendor)	1 representative sample	$1,500
Site Preparation and Support (Site)	Pad construction and accessory rentals	$30,000
Engineering and Administrative (Vendor)	Administrative and assessment	$18,000
Transportation (Vendor)	Plant and personnel mobilization	$28,000
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$20,000
Decontamination and Demobilization (Vendor)	Disassembly, decontamination, and demobilization	$20,000
Total Fixed Costs		$163,500
Variable Costs		
Site Excavation/Hauling (Vendor)	Backhoe equipment, excavation/hauling	$125,000
Equipment Lease (Vendor)	25% depreciation over 4 cleanups	$75,000
Labor (Site)	1 site superintendent for 160 hours	$9,600
	1 health and safety officer for 160 hours	$9,600
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$800
	Water, 25,000 @ $8.07/kgal	$200
	Phone, $200/month	$400
Labor (Vendor) - Operations Crew	1 supervisor for 320 hours	$9,600
	2 technicians for 500 hours	$30,000
Consumables and Supplies (Vendor)	PPE, gloves, tarps, accessories	$2,000
Sampling and Analyses (Site)	Accessories, equipment rental	$4,000
- Labor (Site)	1 technician for 160 hours	$12,800
- Analyses (Site)	50, sample prep and analyses	$12,000
Residuals, Waste shipping and andling (Vendor)	Bulk solid waste & recovered metals credit	$110,000
Effluent Treatment (Site)	Wastewater, 20,000 gal @ $1.25/gal	$25,000
Total Variable Costs		$426,000
Total Project Costs		**$589,500**
Total Cost/Ton of Soil		**$59**
Variable Cost/Ton of Soil		**$43**

Table 6. Cost Comparison of Alternative Technologies

Technology Soil to be Processed	Landfill Disposal Costs 10,000 tons	S/S Costs 10,000 tons	HCl Acid Washing Costs 10,000 tons
Processing Duration	**1 month**	**2 months**	**3 months**
Fixed Costs			
Permitting and Regulatory (Site)	$73,199	$73,199	$73,199
Site Characterization (Site)	$56,171	$56,171	$56,171
Vendor Selection/Contracting (Site)	$25,000	$135,686	$135,686
Bench-Scale Treatability Tests (Vendor)	$0	$17,739	$17,739
Site Preparation and Support (Site)	$15,400	$75,400	$150,839
Engineering and Administrative (Vendor)	$12,000	$41,000	$41,571
Transportation (Vendor)	$52,125	$98,120	$173,692
On-Site Mobilization (Vendor)	$16,500	$22,228	$23,825
Decon and Demob (Vendor)	$12,000	$20,000	$20,000
Total Fixed Costs	$262,395	$539,543	$692,722
Variable Costs			
Site Excavation / Hauling (Vendor)	$1,909,651	$124,190	$124,190
Equipment Lease (Vendor)	$55,250	$138,125	$233,075
Labor (Site) - Superintendent/HSO[a]	$14,400	$14,400	$28,800
Utilities (Site) - Electricity	$750	$750	$1,125
Utilities (Site) - Water	$323	$4,035	$646
Utilities (Site) - Phone	$440	$440	$660
Labor (Vendor) - Operations Crew	$46,525	$86,600	$134,400
Chemicals (Vendor) - HCl Acid	$0	$0	$21,796
Chemicals (Vendor) - Acetic Acid	$0	$0	$0
Chemicals (Vendor) - ThioRed®	$0	$0	$0
Chemicals (Vendor) - NaOH	$0	$0	$30,563
Chemicals (Vendor) - Cement	$0	$204,897	$0
Chemicals (Vendor) - DE	$0	$18,000	$40,000
Chemicals (Vendor) - Flocculant	$0	$0	$26,347
Chemicals (Vendor) - Lime	$0	$0	$712
Consumables and Supplies (Site)	$12,749	$25,497	$50,994
Sampling and Analyses (Site)	$17,437	$17,437	$34,873
- Labor (Site) - Supervisor	$7,200	$14,400	$28,800
- Labor (Site) - Technician	$3,600	$7,200	$14,400
- Analyses (Site) - TCLP/Totals	$6,480	$42,960	$86,040
Residuals, Waste Shipping and Handling (Vendor)	$0	$87,500	$110,180
Effluent Treatment (Site)	$22,250	$44,500	$27,500
Total Variable Costs	$2,095,335	$830,931	$995,364
Total Project Costs	$2,357,730	$1,370,474	$1,688,086
Total Cost/Ton of Soil Processed	$236	$137	$169

(a) HSO is Health and Safety Officer.
DE is diatomaceous earth.

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Fixed costs incurred irrespective of the amount of soil processed include environmental assessment, regulatory permitting, site characterization, bench-scale treatability testing, engineering and administration, site preparation, transportation, mobilization, and demobilization. Variable costs are dependent on the total amount of soil processed and include pro-cess plant lease (vendor), chemicals used, utilities (power and water) required, operating labor, sampling and analysis, consumables and supplies, soil excavation and hauling, and residual disposal.

For future implementation, fixed costs essentially would be independent of the scale of operation. Some savings in vendor selection costs, however, may be possible. Some variable costs would be site-specific. The soil processing rate, which affects the costs incurred for labor, utilities, chemicals and other consumable supplies, depends on soil type. Thus some reductions may be possible. Bulk purchases of consumables may also be feasible for larger operations.

Any recycled metals recovered by the smelter were considered as a credit to the variable cost of residual disposal.

Vendor profit or fee is not shown in the cost projections but is likely to be included in the equipment lease charge.

At the end of Vendor 2's demonstration, the process solution in the regenerated leachant stream was a wastewater that required disposal. Due to dilution with rainwater and further in-plant treatment by the vendor, this could be discharged to the sanitary sewer as non-hazardous waste, and thus no cost was incurred. However, in the full-scale cost projections, an allowance was made for wastewater treatment costs being incurred when the technology is implemented elsewhere. The basis for this cost were the hazardous waste disposal charges incurred for wastewater generated during Vendor 1's demonstration.

6.2 PERFORMANCE OBSERVATIONS

Acetic acid and hydrochloric acid were both found effective for removing lead from soils. However, the efficacy and soil degradation/environmental impact of these acids will vary with soil type and lead specie. These acids perform very differently in leaching metals in the pH <7 region due to their markedly different acid and buffering activity, metal complexing characteristics, and metal oxidation catalysis capability. Generally speaking, hydrochloric acid is an aggressive leachant that is a corrosive and low-cost acid, whereas acetic acid is more selective, far less corrosive, but significantly higher in cost relative to hydrochloric acid. Based on the Fort Polk demonstration, further pursuit of an acetic acid process will require additional bench- and pilot-scale demonstrations to optimize the precipitation step prior to implementation. However, the hydro-chloric acid process is ready for implementation and does not require further development or demonstration.

6.3 OTHER SIGNIFICANT OBSERVATIONS

At sites with less than about 2,600 tons of soil, landfilling is the cheapest option. An off-site technology such as landfilling, is always cheaper than on-site technologies at smaller sites, mainly because of higher on-site fixed costs for site preparation, plant equipment, etc. At larger sites, as the fixed costs are spread out over a larger tonnage of soil processed, on-site technologies become cheaper. Among on-site technologies, solidification/stabilization is cheaper than physical separation/acid leaching regardless of the amount of soil processed because stabilization uses simpler equipment and therefore incurs lower capital costs.

Several benefits of physical separation and acid leaching may outweigh the cost advantage of landfilling or solidification/stabilization, irrespective of the amount of soil requiring processing, and these should be considered by sites trying to identify the best alternative:

- With landfilling and solidification/stabilization, although the metals have been immobilized or contained, the liability remains. With physical separation and acid leaching, over 95% of the lead may be removed, recovered, and reused.

- Physical separation alone may be sufficient for range maintenance activities.

- Solidification/stabilization of an active range may result in a hardened treated material that is physically unsuitable for reuse in the berm. The processed soil from physical separation and acid leaching still retains its loose texture and can be returned to an active berm.

6.4 REGULATORY ISSUES

Since the range is active, the demonstration was designated not as a remediation activity but as routine range maintenance involving the removal and recycling of the accumulated metals fragments. Nonetheless, a number of applicable regulatory drivers, permits, and reporting requirements were addressed during the demonstration. These include the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA), the EPA Military Munitions Rule, the DoD Military Range Rule, the Emergency Planning and Community Right-to-Know Act (EPCRA), the Clean Water Act (CWA), the Clean Air Act Amendments (CAAA), and the Occupational Safety and Health Act (OSHA).

At active ranges, soil processing activities can be implemented as range maintenance under the EPA Military Munitions Rule and the DoD Military Range Rule, as long as the processed soil is reusable in the berm. In inactive ranges, any soil processing is likely to come under RCRA. In addition, states such as California, may have more stringent requirements. The California Wet Extraction Test (WET), which uses stronger leaching conditions than the TCLP test, is used to determine acceptable levels of heavy metals in remediated soil. If regulatory targets for on-site reuse of processed soil were significantly lower than about 150 mg/kg total lead and 5 mg/L (TCLP) leachable lead, the technical and cost challenges facing this technology would increase.

In addition, NEPA applies to any maintenance or remediation activity at active or inactive small-arms ranges. However, because of the limited scope of many range projects, it may be possible (as at Fort Polk) to fulfill

NEPA requirements by applying a CATEX with a REC, as described in Chapter 4 of Army Regulation (AR) 200-2 (Ref. 5).

Independent efforts are underway now, via the Interstate Technology and Regulatory Cooperation (ITRC) Working Group, to demonstrate to federal and state regulatory groups the capabilities of this new technology set and to satisfactorily demonstrate its effectiveness, implementability, and cost competitiveness.

6.5 LESSONS LEARNED

The following factors contributed to the low plant reliability and inability of Vendor 1 to meet processing targets:

- ***Inadequate bench-scale testing.*** Precipitation efficiency was not optimized during the bench-scale tests and key operating parameters, such as precipitant dosage and effective pH range, had not been determined by prior bench-scale testing. At bench-scale itself, Vendor 1 was unable to optimize the separation/leaching processes to attain the TCLP lead target.

- ***Inadequate process control.*** The problem with the buildup of lead in the leachant was not identified and corrected in time during the demonstration because the vendor's atomic absorption (AA) analyzer was not functional, and there was no other means to provide reliable on-site verification. Additional operators would have provided better process control.

- ***Inadequate attention to material handling and equipment sizing during plant design.*** Various material handling problems (in the feed hopper, plate feeder, soil deagglomerator, sand screw, vacuum belt filter, and plate-and-frame filter press) were encountered, which caused frequent bottlenecks and downtime.

The following on-site plant modification was made by Vendor 2 after initial soil processing.

Because of difficulties encountered in screening the raw soil, Vendor 2 eliminated the screening unit and the coarse material jig from the planned plant configuration. Instead, the raw soil was sent directly to the attrition scrubber and classifier. The coarse fraction from the classifier was sent to the fine material jig. The metals collected in the jig bed (stream MN) were an unexpected process stream that resulted from these on-site modifications made to the plant by the vendor.

Plant design should be flexible enough to handle the expected variability in the texture and metals content of the soil. Adequate process control should be built into the plant to enable personnel to verify that operating parameters established during bench-scale testing are being met in the field.

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APPENDIX A

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